REMARKS

Claims 1-34 are pending in the present application. Independent Claims 1 and 15 and dependent Claim 12 have been amended to correct scrivener's errors. Amended Claims 1 and 15 are at least as broad as original independent Claims 1 and 15 and these amendments should not be construed as narrowing the scope of the Claims.

Claims 7, 20 and 25

Applicant respectfully requests that Claims 7, 20 and 25 be examined on the merits.

Claim Rejections pursuant to 35 U.S.C. §102(e)

Claims 1, 15 and 26 stand rejected pursuant to 35 U.S.C. §102(b) as being anticipated by U.S. Patent No. 5,598,480 to Kim (hereinafter "Kim"). Applicant respectfully traverses these rejections for at least the following reasons because Kim fails to teach the invention described in the claims.

Claim 1

Amended Claim 1 provides a loudspeaker system for receiving an incoming electrical signal and transmitting an acoustical signal. The loudspeaker system includes a driver circuit having an input with an input impedance. The driver circuit includes a first passive filter coupled to a first speaker driver and a second passive filter coupled to a second speaker driver. In addition, the loudspeaker system includes a power amplifier having an input and an output with an output impedance that is between about 25 percent and about 400 percent of the input impedance of the driver circuit. The input of the power amplifier receives the incoming electrical signal, and the output of the power amplifier is coupled to the input of the driver circuit.

Kim teaches a power amplifier with outputs coupled to the input terminals of a remote speaker unit via a pair of extension leads. (Figs. 1 – 2, Col. 2 lines 61-66, Col. 3 lines 26-31) In stark contrast to Claim 1, however, Kim makes no mention of an output impedance that is between about 25 percent and about 400 percent of the input impedance of the driver circuit as provided in Claim 1. In fact, Kim only briefly mentions the power amplifier and is instead focused on the

speaker unit. Kim's brief discussion of the power amplifier describes the power amplifier as an "output audio amplifier of a typical sound reproducing unit." (Col. 2 lines 61-62)

In the detailed description of the present application, a typical commercial amplifier is described as a voltage source amplifier. Voltage source amplifiers have an output impedance near zero ohms. (specification P. 5 paragraph 11 and P. 9 paragraph 34) As is well known in the art, an ideal voltage source having an output impedance of zero ohms provides non-varying output voltage while providing varying amounts of current. Although commercial amplifiers are not ideal voltage sources, in general, the lower the output impedance of the amplifier the more accurate the reproduction of audible sound from a variable impedance loudspeaker being driven by an audio signal generated by a power amplifier. (Attachment A p. 93)

The output impedance of an audio power amplifier is described in terms of a damping factor. (Attachments B p. 4 of 5 and C) The damping factor provides an indication of the amplifiers performance capability with respect to a variable load being driven by the amplifier. (Attachment B p. 4 of 5) An amplifier with an output impedance that is closer to zero has lower sensitivity to impedance variations of the load. (Attachment A p. 93) As a result, the frequency response of the driven load will be flat and distortion will be minimized. The damping factor is based on both the output impedance of the amplifier and the impedance of the load:

damping factor = load impedance/amplifier output impedance.

(Attachment C)

Accordingly, a lower damping factor (amplifier output impedance) usually reflects a higher quality amplifier. (See Attachment B) Current source amplifiers, on the other hand, typically have an output impedance near infinity. (specification P. 5 paragraph 11) Although not nearly as prevalent in audio power amplifiers, an ideal current source amplifier maintains a constant current as the voltage varies. Accordingly, for the same reason the output impedance of a voltage source amplifier is desirably low, the output impedance of a current amplifier is desirably high, and is infinity in an ideal current amplifier.

Today's voltage source amplifiers typically have an output impedance of less than 5% of the load, although output impedances of less than 20% of the load impedance were documented with older vacuum tube electronic designs to provide for feedback execution. (Attachment D p. 25, See also Attachment C p. 2) An example voltage source amplifier is described in the present application as having an output impedance of 5 milli-Ohms. (specification P. 9 paragraph 34) Thus, the typical voltage amplifier described by Kim would <u>not</u> have an output impedance that is between about 25%

and 400% of the input impedance of a driver circuit as described in Claim 1. In fact, Kim fails to teach, suggest or disclose any correlation between the output impedance of a power amplifier and the input impedance of a driver circuit.

In the office action, it has been asserted that Fig. 1 of Kim teaches a power amplifier with an output having an output impedance between about 25% and 400% of the input impedance of a driver circuit. After careful review of Fig. 1, Applicant respectfully disagrees. Fig. 1 of Kim makes no reference to any impedance value associated with the power amplifier nor any of the circuit elements schematically represented in Fig. 1. In fact, Kim never provides <u>any</u> damping factor and/or impedance values of the power amplifier or the other circuit elements illustrated in Fig. 1. Accordingly, those skilled in the art would understand that a "typical power amplifier" as described by Kim would be a voltage source power amplifier having an output impedance of less than 5%.

For at least the foregoing reasons, Claim 1 is patentably distinct in view of the cited prior art. Accordingly, Applicant respectfully requests removal of the 35 U.S.C. §102(b) rejection of Claim 1. Dependent Claims 2-14 depend from independent Claim 1 and are therefore also patentably distinct.

<u>Claim 15</u>

Amended Claim 15 provides a method of constructing a loudspeaker system for receiving an incoming electrical signal and transmitting an acoustical signal. The method includes selecting a first speaker driver having a first cold impedance and selecting a second speaker driver having a second cold impedance. The method also includes constructing a first passive filter having an input and an output and constructing a second passive filter having an input and an output. In addition, the method includes the coupling the output of the first passive filter to the first speaker driver so that the input of the first passive filter has a first combined cold impedance, and coupling the output of the second passive filter to the second speaker driver so that the input of the second passive filter has a second combined cold impedance. Forming a passive arrangement of the first speaker driver, the second speaker driver, the first passive filter and the second passive filter by coupling the input of the first passive filter to the input of the second passive filter is also provided by the method. The passive arrangement has an arrangement cold impedance. In addition, the method describes constructing a power amplifier having an input for receiving said incoming electrical signal and an output. The output has an output impedance that is between about 25 percent and about 400 percent

of the arrangement cold impedance. The method also includes coupling the output of the power amplifier to the input of the first passive filter and to the input of the second passive filter.

In contrast, Kim fails to teach, suggest, or disclose constructing a power amplifier having an output with an output impedance that is between about 25 percent and about 400 percent of a cold impedance of an arrangement formed with a first speaker driver and a second speaker driver as described in Claim 15. As previously discussed, Kim provides no teaching or suggestion related to the impedance relationship between the output impedance of a power amplifier and the cold impedance of an arrangement of a first and second passive filter as further provided in Claim 15. For at least the foregoing reasons, Claim 15 is patentably distinct in view of the cited prior art. Accordingly, Applicant respectfully requests removal of the 35 U.S.C. §102(b) rejection of Claim 15. Dependent Claims 16-25 depend from independent Claim 15 and are therefore also patentably distinct.

Claim 26

Claim 26 provides a loudspeaker system for receiving an incoming electrical signal and transmitting an acoustical signal. The loudspeaker system includes an amplification means for receiving the incoming electrical signal at an input and providing an amplified signal that is a function of the incoming electrical signal at an output that has an output impedance. The system also includes a first filter means for receiving the amplified signal at an input and providing a first filtered signal that is a function of the amplified signal at an output and a second filter means for receiving the amplified signal at an input and providing a second filtered signal that is a function of the amplified signal at an output. In addition, the system includes a first speaker driver coupled to the output of the first filter means. The first speaker driver has a first cold impedance and is driven by the first filtered signal. The system also includes a second speaker driver coupled to the output of the second filter means. The second speaker driver is driven by the second filtered signal. The output impedance of the amplification means is between about 25 percent and about 400 percent of the first cold impedance.

In contrast, Kim fails to teach, suggest or disclose amplification means with an output impedance between about 25 percent and about 400 percent of a cold impedance of a first speaker driver as provided in Claim 26. Thus, Claim 26 is not taught, suggested or disclosed by the cited prior art. Applicant therefore respectfully requests removal of the 35 U.S.C. §102(b) rejection of

Claim 26. Dependent Claims 27-30 depend from independent Claim 26 and are therefore also not taught, suggested, or disclosed by the cited prior art.

The 35 U.S.C. 103(a) Claim Rejections

Pending Claims 2, 3, 16 and 17 stand rejected pursuant to 35 U.S.C. 103(a) as being obvious in view of Kim and further in view of U.S. Patent No. 4,504,704 to Ohyaba et al. (hereinafter "Ohyaba"). In addition, pending Claims 4, 5 and 18 stand rejected pursuant to 35 U.S.C. 103(a) as being obvious in view of Kim and further in view of U.S. Patent No. 4,751,738 to Widrow et al. (hereinafter "Widrow"). Also, Claims 8, 19, 27, 28 and 32 stand rejected pursuant to 35 U.S.C. 103(a) as being obvious in view of Kim and further in view of U.S. Patent No. 5,097,223 to Alexander(hereinafter "Alexander 223"). Pending Claims 6 and 29 also stand rejected pursuant to 35 U.S.C. 103(a) as being obvious in view of Kim.

Claim 9 stands rejected pursuant to 35 U.S.C. 103(a) as being obvious in view of Kim and further in view of published U.S. Patent Application 2002/0097097 to Suguira (hereinafter "Suguira 97"). In addition, Claims 1-13 and 21-24 stand rejected pursuant to 35 U.S.C. 103(a) as being obvious in view of Kim and further in view of U.S. Patent No. 6,381,334 to Alexander(hereinafter "Alexander 334"). Pending Claim 14 stands rejected pursuant to 35 U.S.C. 103(a) as being obvious in view of Kim and further in view of published U.S. Patent Application 2004/0101153 to Grudin et al. (hereinafter "Grudin"). In addition, pending Claim 30 stands rejected pursuant to 35 U.S.C. 103(a) as being obvious in view of Kim and further in view of U.S. Patent No. 6,661,290 to Suguira (hereinafter "Suguira 290"). Claim 31 stands rejected pursuant to 35 U.S.C. 103(a) as being obvious in view of Kim, Alexander 223 and Grudin.

Applicant respectfully traverses these rejections for at least the foregoing reasons and also the following reasons. Specifically, Applicant respectfully asserts that all of the features provided in Claims 2-6, 8-14, 16-19, 21-24 and 27-32 are not taught or suggested by the cited prior art. Thus, a *prima facie* case of obviousness has not been established.

Claim 31

Claim 31 provides a loudspeaker system for receiving an incoming electrical signal and transmitting an acoustical signal. The loudspeaker system includes a driver circuit having a cold input impedance and a current feedback amplifier having an output impedance that is substantially

matched to the cold input impedance of the driver circuit. The system also includes a speaker enclosure housing the driver circuit and the current feedback amplifier. The current feedback amplifier receives the incoming electrical signal and drives the driver circuit.

In the office action, it was asserted that the combination of Kim and Alexander 223 teach a current feedback amplifier having an output impedance that is substantially matched to the cold input impedance of a driver circuit as described in Claim 31. Applicants respectfully disagree that either of the cited references teach that an output impedance is substantially matched to a cold input impedance of a driver circuit. As previously discussed, Kim includes no discussion regarding impedances or damping factors. Similarly, Alexander 223 includes no such discussion. In contrast, Alexander 223 describes a conventional current feedback amplifier (Col. 4 lines 34-62) As previously discussed, those skilled in the art would understand such an amplifier has a very high output impedance (close to infinity) in an effort to achieve an ideal current source that will not vary as the load impedance varies. Clearly, an output impedance that is substantially matched to a cold impedance of a driver circuit as described in Claim 31 is not close to infinity.

Based on the foregoing, all of the claim features disclosed by Claim 31 are not taught or suggested by either Kim, Alexendar 223 or Grudin either alone or in combination. Thus, a *prima facie* case of obviousness has not been established for Claim 31. Accordingly, Applicant respectfully requests the removal of the 35 U.S.C. §103(a) rejection of Claim 31.

Claim 32

Claim 32 provides a method of operating a loudspeaker system that converts an incoming electrical signal to an acoustical signal. The method includes operating a driver circuit in a temperature range so that an input impedance of the driver circuit is in an operational range. The method also includes configuring an output impedance of a current-feedback amplifier to be within the operational range of the input impedance of the driver circuit. In addition, the method includes amplifying the incoming electrical signal with the current-feedback amplifier to produce a driving electrical signal and driving the driver circuit with the driving electrical signal.

In contrast, neither Kim nor Alexander 223 either alone or in combination teach, suggest or disclose configuring an output impedance of a current-feedback amplifier to be within the operational range of the input impedance of a driver circuit as described in Claim 32. Accordingly, all of the claim features disclosed by Claim 32 are not taught or suggested by either Kim or Alexendar 223 alone or in combination. Thus, a *prima facie* case of obviousness has not been

established for Claim 32. Accordingly, Applicant respectfully requests the removal of the 35 U.S.C. §103(a) rejection of Claim 32.

Claims 9-14, 22, 24 and 30

Claim 9 further describes that the power amplifier of Claim 1 comprises a voltage source amplifier having a ballast resistor with a resistance between about 25 percent and about 400 percent of the input impedance of the driver circuit. In the office action, it has been asserted that Suguira 97 teaches a ballast resistor. Aside from the fact that Suguira 97 is directed to high frequency amplifiers, Suguira 97 fails to teach, suggest, or disclose a ballast resistor with a resistance between about 25 percent and about 400 percent of the input impedance of the driver circuit as provided in Claim 9. In fact, Suguira 97 teaches that the ballast resistors are used as part of the biasing scheme for a power amplifier <u>input</u> (paragraph 11) in contrast to a voltage source amplifier having a ballast resistor as described in Claim 9. Further, the bias resistor of Suguira 97 is clearly not coupled in series with the output of a voltage source amplifier and the input of a driver circuit as described in Claim 33.

Claim 10 further describes that the first speaker driver of Claim 1 has a cold impedance of about 4 Ohms and that the first passive filter has an output characteristic termination impedance of about 4 Ohms. In addition, the output impedance of the power amplifier of Claim 1 is between about 1 Ohms and about 16 Ohms. Claim 11 further provides that the output impedance of the power amplifier is between about 2 Ohms and about 8 Ohms. Claim 12 provides that the output impedance of the power amplifier is between about 2 Ohms and about 32 Ohms and Claim 13 provides that the output impedance of the power amplifier is between about 4 Ohms and about 16 Ohms.

In the office action, it was asserted that Kim taught that the output impedance of the power amplifier is between the impedances claimed in Claims 10-13. Applicant respectfully traverses these assertions since, as previously discussed, Kim fails to provide any teaching or suggestion with regard to the output impedance of a power amplifier. The office action has further asserted that it would have been obvious to one skilled in the art to have the output impedance of the power amplifier match the impedance of a driver. Applicant respectfully traverses this assertion since, as previously discussed, those skilled in the art strive for a power amplifier with zero impedance (voltage source amplifier) or infinite impedance (current source amplifier) to minimize distortion. In fact, in the office action, it is asserted that matching the output impedance of the power amplifier

to the filter termination impedance would be obvious "in order to prevent the output impedance from negatively effecting the frequency response." This is exactly opposite of the motivation to minimize the output impedance (voltage power amplifier) or maximize the output impedance (current power amplifier) in order to improve the frequency response. (See Attachments A, B, C and D)

Claim 22 similarly describe an output impedance of a power amplifier that is between about 2 Ohms and about 8 Ohms. Claim 24 similarly describes an output impedance of a power amplifier that is between about 2 Ohms and about 16 Ohms. Accordingly, Claims 22 and 24 are also not taught, suggested or disclosed by the cited prior art, as previously discussed with regard to Claims 10-13. In addition Claim 28 describes a current-feedback amplifier having an output impedance between about 2 Ohms and about 16 Ohms. Clearly, none of the cited prior art either alone or in combination teaches anything regarding the output impedance of a current amplifier. Thus, Claim 28 is not taught, suggested or disclosed by the cited prior art.

With regard to amended Claim 30, it has been asserted that Suguira 97 teaches a ballast resistor, and that it would have been obvious to "have a resistance as claimed [in Claim 30] in order to have an efficient loudspeaker." Applicant respectfully traverses this assertion since the ballast resistor of Claim 30 is not providing efficiency as asserted by the office action. In fact, the ballast resistor of Claim 30 "may dissipate approximately half of the output power of the amplifier." (specification paragraph 41 page 12) Accordingly, any efficiency taught by Suguira 97 resulting from use of a ballast resistor teaches away from use of the ballast resistor described in Claim 30.

For at least the foregoing reasons, all of the claim features disclosed by Claims 9-13, 22, 24, 28 and 30 are not taught or suggested by either Kim, Alexendar 223 or Suguira 97 alone or in combination. Thus, a *prima facie* case of obviousness has not been established for these Claims. Accordingly, Applicant respectfully requests the removal of the 35 U.S.C. §103(a) rejection of Claims 9-13, 22, 24, 28 and 30.

With regard to Claims 33-34, none of the cited prior art either alone or in combination teach, suggest or disclose the claimed features, and therefore Claims 33-34 are also patentable over the prior art of record. With this amendment and response, Applicant believes that the present pending claims of this application are allowable and respectfully requests the Examiner to issue a Notice of

Allowance for this application. In the event a telephone conversation would help expedite the prosecution/allowance of this application, the Examiner may contact the undersigned at (317) 636-0886.

Respectfully submitted,

Sanders N. Hillis
Attorney for Applicant
Attorney Reg. No. 45,712

Attachments A (4 pgs.), B (5 pgs.), C (3 pgs.) and D (6 pgs.)

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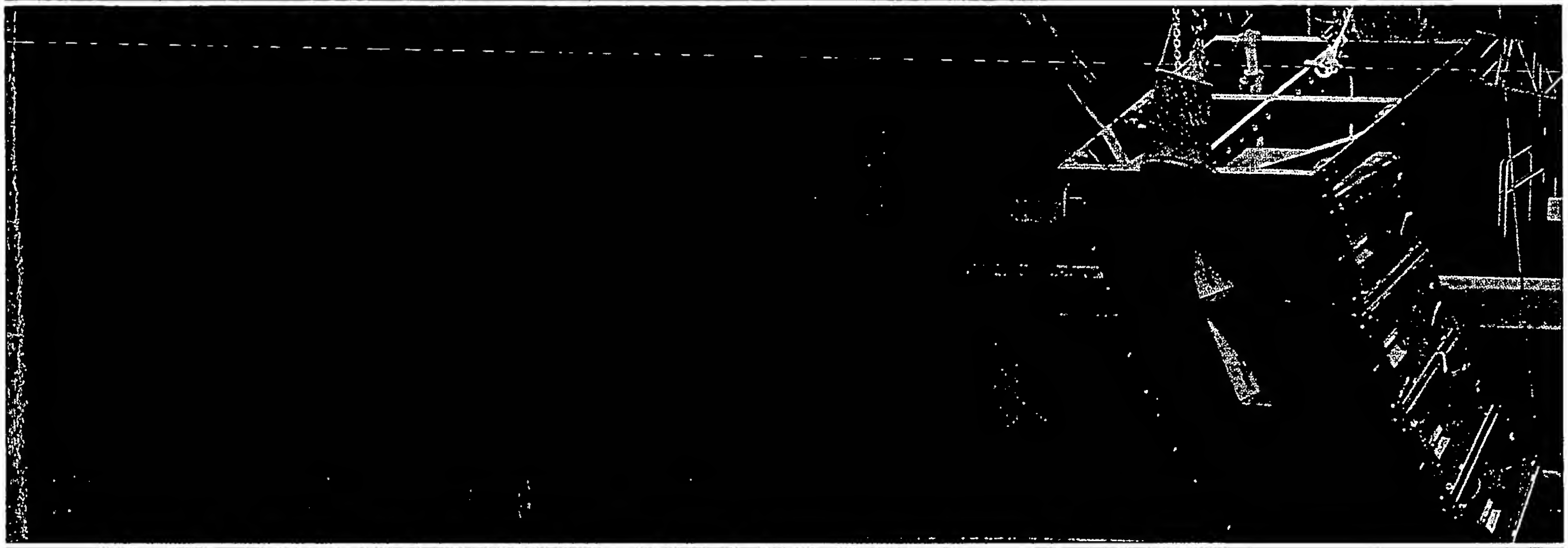
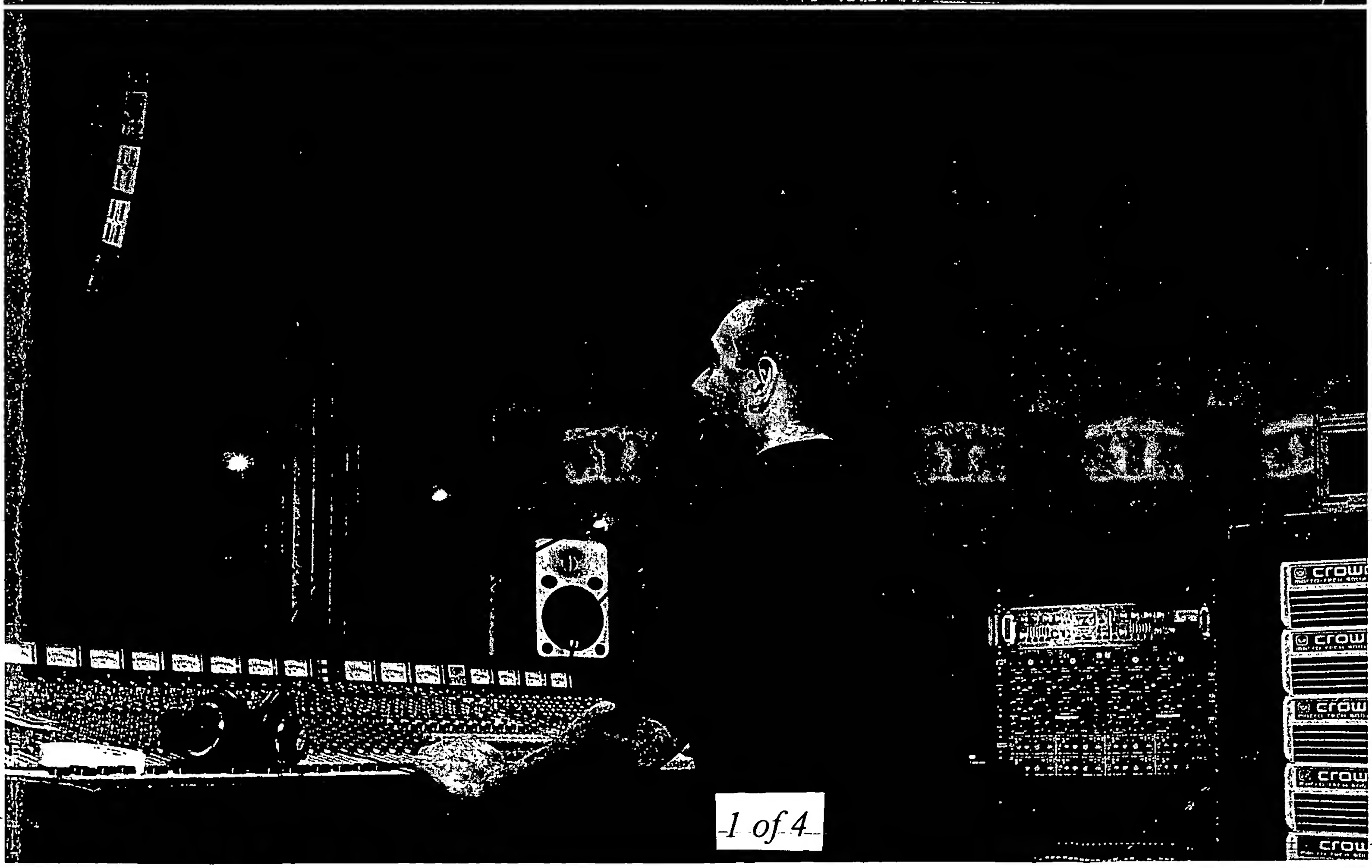
ATTACHMENT A

Pages 1-4

Excerpt from Chapter 7, Pages 93-94
Of
JBL AUDIO ENGINEERING FOR SOUND REINFORCEMENT

AUDIO for sound reinforcement





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In bridged mode the amplifier carries only a single rating, and that is given for an 8-ohm load only. DO NOT attempt to use a bridged amplifier for any loads of lower impedance than those specified by the manufacturer!

Input and output connections; impedances and sensitivity

Amplifiers intended for professional use will normally have XLR-F signal input receptacles, and output connections are usually by way of 5-way binding posts, as shown in Figure 7-4. Some stereo amplifiers provide in addition a stereo (4-conductor) Neutrik Speakon output receptacle.

The input impedance of a typical professional amplifier is in the range of 10,000 to 20,000 ohms. The amplifier thus constitutes a bridging load on the device which immediately precedes it. Because there is a buffer stage at the input of the amplifier, there will be a maximum signal voltage that may be applied at the input. This is normally in the range of 24 dBu (12.5 Vrms). Many manufacturers do not specify this limit inasmuch as good engineering practice in systems design and layout pretty much precludes such a high signal level at that point in the audio chain. Nevertheless, a careful design engineer will want to know exactly what the limit is.

The amplifier's output impedance is measured in fractions of an ohm, and the specification we normally see here is the damping factor of the amplifier. Damping factor is defined as the load impedance divided by the amplifier's output impedance:

$$\text{Damping factor} = Z_L/Z_0 \qquad 7.1$$

Damping factor is a measure of how well the amplifier handles reactive loads, many of which produce back-voltages into the amplifier's output stage. A typical amplifier may have a damping factor in the range of 200 when connected to an 8-ohm load, and this corresponds to an output impedance of 8/200, or 0.04 ohm, indicating that the amplifier's output voltage is quite insensitive to normal loudspeaker load impedance variations. Details of input and output impedance are shown in Figure 7-5.

The maximum output sensitivity of an amplifier is measured with its input attenuator set to its reference position. Sensitivity is then defined as the rms signal voltage applied at the input which will produce maximum power output into a reference load. As a general rule, most professional amplifiers require an input voltage in the range of 1.23 (+4 dBu) to drive the amplifier to full output.

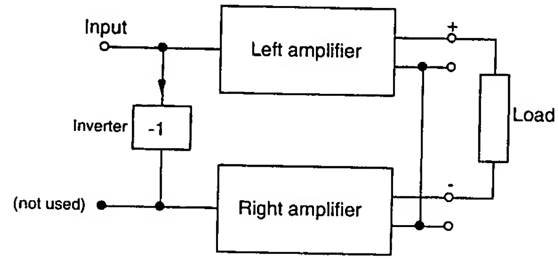

Figure 7-3: Amplifier bridging.

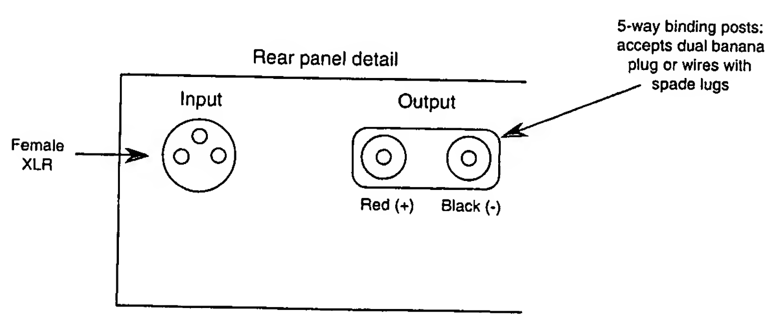

Figure 7-4: 5-way binding post at the output of a power amplifier.

Amplifier noise floor

The noise rating for an amplifier is normally stated as its nominal level in dB below full output. A typical professional amplifier has a noise rating of 100 dB below full output. Assuming that full output for an amplifier is stated as 400 watts into 4 ohms. How will this rating actually affect the amplifier's performance in a typical installation?

Let us assume that the amplifier directly drives a loudspeaker system which has a reference output sensitivity of 100 dB, one watt measured at one meter. Hypothetically, at least, the full output of the amplifier will produce a level of 126 dB, as measured at one meter from the loudspeaker, provided it can handle the power fed to it. The loudspeaker will then produce a noise level (under no-signal conditions) which will be 100 dB below 126 dB, which will be 26 dB, as measured at one meter. Details of this are shown in Figure 7-6.

Although 26 dB may sound like a large number, it is in fact a very low value when we consider that the loudspeaker will probably be listened to at distances approaching 10 meters, where the level will be about 20 dB lower, or 6 dB. On the SPL acoustical scale, 6 dB is well below the residual noise floor in a good studio or concert hall; therefore, amplifier noise levels are rarely likely to be of any concern in sound reinforcement.

Amplifier mounting and cooling requirements

Most professional amplifiers are designed for fixed mounting in standard (19-inch) racks. Depending on its design parameters, the amplifier may produce a good bit of heat which must be effectively removed. For many designs, normal convection paths inside the rack will be sufficient if the rack is properly vented at the top. Some larger amplifier models have internal fans, which may be engaged automatically when the amplifier reaches a certain operating temperature. Fans however may be noisy and disturbing to nearby operators, especially in critical control room and other monitoring environments. These matters will be discussed in greater detail in chapters dealing with systems engineering.

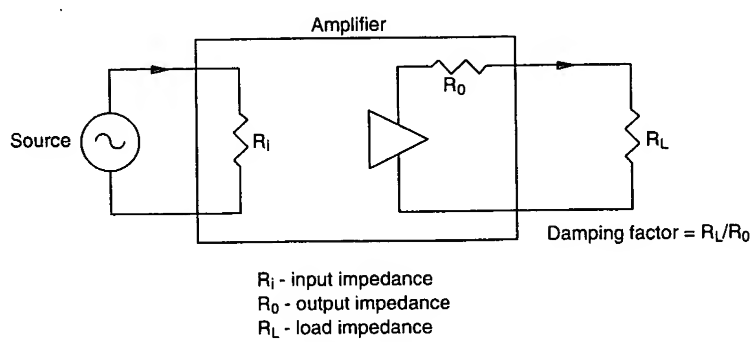

Figure 7-5: Amplifier input impedance, output impedance and damping factor.

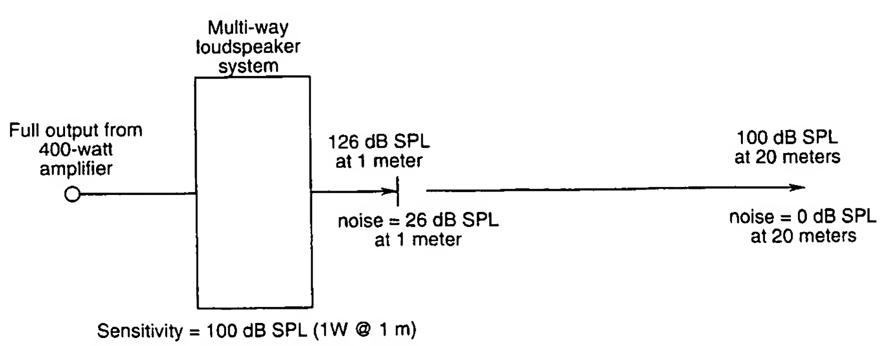

Figure 7-6: Effect of amplifier noise on the acoustical output signal.

ATTACHMENT B

Pages 1-5

Understanding Damping Factor, from
http://www.crownaudio.com/amp_htm/ampinfo.htm

Crown Amplifier Technical Information

Viewing PDF files requires Adobe Acrobat. Get Acrobat Reader

- Technical Papers
- Power Draw and Thermal Dissipation Info

AMPLIFIERS

FAQs

Technical Info & How To

Technical Papers

Crown has long been leading the audio industry with innovative technologies that provide economical solutions to real world needs. Following are Technical Papers describing technologies used in Crown amplifiers.

Balanced Current Amplifier Technology

- **BCA Technology Overview** (HTML Format)
- **BCA White Paper** (138K PDF Format)

Other Crown Amplifier Technologies

- **IOC Distortion Detector** (31K PDF Format)
- **Why Crown CTs Amplifiers Sound Better** (HTML Format)
- **Advantages of Direct Constant Voltage Operation in Crown Amplifiers** (HTML Format)
- **Understanding Damping Factor** (63K PDF Format)
- **Grounded Bridge Topology** (102K PDF Format)
- **ODEP (Output Device Emulation Protection)** (39K PDF Format)
- **Spoof Amplifier Data Sheet (BF-6000 SUX)** (207K PDF Format)
- **UL, CSA, ETL, and CE: What's the Difference?** (HTML format)
- **Regulatory Certification Marks on Crown Products** (HTML format)
- **What's a Crown Watt?** (HTML format)
- **Audio Networking** (HTML format)

1 of 5

Tech Made Simple

Clear explanations of Crown technical features, condensed to one page per topic.

- **Class I (BCA)** (42.5K PDF Format)
- **Damping Factor** (35.6K PDF Format)
- **The V-I Plane** (43.0K PDF Format)
- **Certification Marks (Safety Standards)** (38.0K PDF Format)
- **What is TCP/IQ?**
- **What is CobraNet?**
- **Switching Power Amplifiers and Switching Power Supplies**
- **I-Tech: So Much Power, So Little Current Draw**
- **Gain Staging**
- **Matching Speaker Loads to Amplifiers**
- **I-Tech Power Specs: Why 2-ohm Power is Less Than 4- and 8-ohm Power**

Power Draw and Thermal Dissipation Information

The following documents provide detailed information about the amount of power and current drawn from the AC mains by Crown amplifiers and the amount of heat produced under various conditions. The calculations presented are intended to provide a realistic and reliable depiction of the amplifier. This information should not be construed as specifications.

All of the following documents are in Adobe PDF format.

CE Series	CE 1000/2000 Calculated Data Sheet CE 4000 AC Power & Thermal Sheet
Com-Tech Series	CT-210 Calculated Data Sheet CT-410 Calculated Data Sheet CT-810 Calculated Data Sheet CT-1610 Calculated Data Sheet
Contractor Series	CH1 AC Power & Thermal Sheet CH2 AC Power & Thermal Sheet CH4 AC Power & Thermal Sheet CL1 AC Power & Thermal Sheet CL2 AC Power & Thermal Sheet CL4 AC Power & Thermal Sheet
	CTs 600 AC Power & Thermal Sheet

CTs Series	CTs 1200 AC Power & Thermal Sheet CTs 2000 AC Power & Thermal Sheet CTs 3000 AC Power & Thermal Sheet CTs 4200 AC Power & Thermal Sheet CTs 8200 AC Power & Thermal Sheet
I-Tech Series	I-Tech Series AC Power & Thermal Sheet
K Series	K Series Calculated Data Sheet
Macro-Tech Series	MA-602 AC Power & Thermal Sheet MA-1202 AC Power & Thermal Sheet MA-2402 AC Power & Thermal Sheet MA-3600VZ Calculated Data Sheet MA-5002VZ AC Power & Thermal Sheet MA-24x6 Calculated Data Sheet MA-36x12 Calculated Data Sheet
Micro-Tech Series	MT-600 Calculated Data Sheet MT-1200 Calculated Data Sheet MT-2400 Calculated Data Sheet
Power Tech .1 Series	PT 1.1 AC Power & Thermal Sheet PT 2.1 AC Power & Thermal Sheet PT 3.1 AC Power & Thermal Sheet
Studio Reference Series	Studio Reference Series Calculated Data Sheet
Xs Series	Xs500 AC Power & Thermal Sheet Xs700 AC Power & Thermal Sheet Xs900 AC Power & Thermal Sheet Xs4300 AC Power & Thermal Sheet Xs1200 AC Power & Thermal Sheet

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UNDERSTANDING DAMPING FACTOR

Loudspeakers have a mind of their own. You send them a signal and they add their own twist to it. They keep on vibrating after the signal has stopped, due to inertia. That's called "ringing" or "time smearing."

In other words, the speaker produces sound waves that are not part of the original signal.

Suppose the incoming signal is a "tight" kick drum with a short attack and decay in its signal envelope. When the kick-drum signal stops, the speaker continues to vibrate. The cone bounces back and forth in its suspension. So that nice, snappy kick drum turns into a boomy throb.

Fortunately, a power amplifier can exert control over the loudspeaker and prevent ringing. Damping is the ability of a power amplifier to control loudspeaker motion. It's measured in Damping Factor, which is load impedance divided by amplifier output impedance. Let's explain.

If the speaker impedance is 8 ohms, and the amplifier output impedance is 0.01 ohms, the damping factor is 800. That's a simplication. Since the speaker impedance and amplifier output impedance vary with frequency, so does the damping factor. Also, the impedance of the speaker cable affects damping. Thick cables (with low AWG) allow more damping than thin cables with (high AWG).

The lower the amplifier's output impedance, the higher the damping factor, and the tighter the sound is. A damping factor of 1000 or greater is considered high. High damping factor equals tight bass.

How It Works

How does an amplifier control speaker motion? When the loudspeaker cone vibrates, it acts like a microphone, generating a signal from its voice coil. This signal generated by the speaker is called back EMF (back Electro Motive Force). It travels through the speaker cable back into the amplifier output, then returns to the speaker. Since back EMF is in opposite polarity with the speaker's motion, back EMF impedes or damps the speaker's ringing.

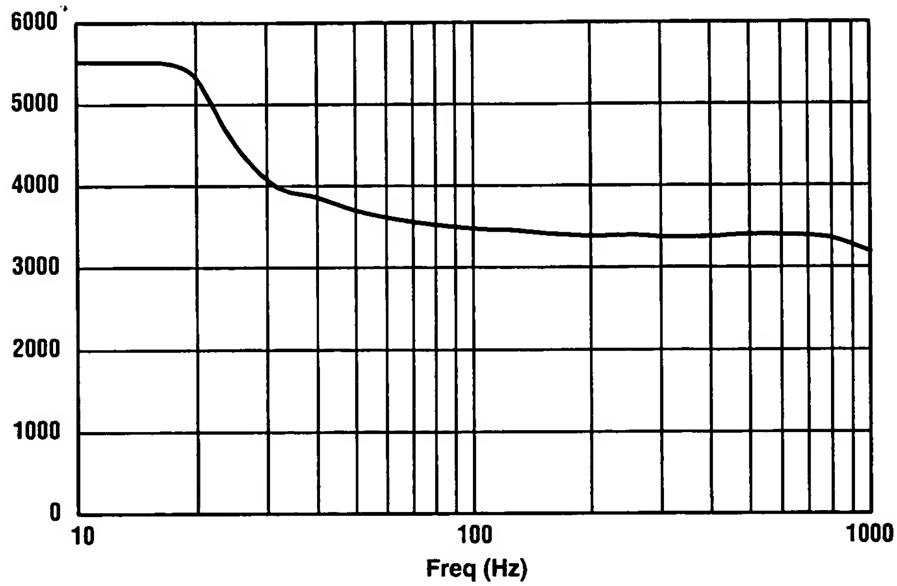
The smaller the amp's output impedance, the greater is the effect of back EMF on the speaker's motion. An amplifier with low output impedance does not impede the back EMF, so the back EMF drives the loudspeaker with a relatively strong signal that works against the speaker's motion. When the speaker cone moves out, the back EMF pulls the speaker in, and vice versa.

In short, the loudspeaker damps itself through the amplifier output circuitry. The lower the impedance of that output circuitry, the more the back EMF can control the speaker's ringing.

To prove it to yourself, take a woofer that is not connected to anything. Put your ear next to the cone and tap on it. You might hear a low-pitched "bongggg" if the speaker itself is poorly damped. Now short the speaker terminals and tap again. You should hear a tighter thump.

Damping factor varies with frequency. As you might suspect, damping factor is most important at low frequencies, say 10 Hz to 400 Hz. The chart on the next page shows typical damping factor vs. frequency of a Crown CTs 600/1200 power amplifier. It's well over 3000 from 10 Hz to 1 kHz.

All Crown amplifiers are designed to have high damping factor. That's why you can count on Crown amps to deliver clean, tight kick drum and bass.



Typical damping factor vs. frequency of a Crown CTs 600/1200 power amplifier.

<u>ATTACHMENT C</u>

Pages 1-3

<u>OUTPUT IMPEDANCE</u>, from
http://encyclopedia.thefreedictionary.com/Output+impedance

Output impedance

The **output impedance**, **source impedance**, or **internal impedance** of an electronic device is the opposition exhibited by its output terminals to the flow of an alternating current (AC) of a particular frequency as a result of resistance, induction and capacitance.

The impedance at DC (frequency of 0) is the same as the resistance component of the impedance.

It is important to realize that no real device (battery, generator, amplifier) is a perfect source; all have an internal impedance, though this may have negligible effect, depending on the load.

Depending on perspective, this impedance appears in series with a perfect voltage source, or in parallel with a perfect current source (*see*: Thevenin's theorem, Norton's theorem).

For example, a preamplifier with 100 ohms output impedance means the output voltage signal appears to be in series with a 100 ohm resistor.

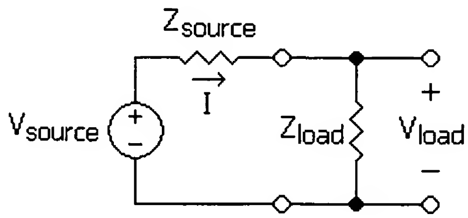
Measurement

The source resistance of a purely resistive device can be experimentally determined by increasingly loading the device until the voltage across the load (AC or DC) is 1/2 of the open circuit voltage. At this point, the load resistance and internal resistance are equal.

It can more accurately be described by keeping track of the voltage versus current curves for various loads, and calculating the resistance from Ohm's law. (The internal resistance may not be the same for different types of loading, especially in devices like chemical batteries.)

The generalized source impedance for a reactive (inductive or capacitive) source device is more complicated to determine, and is usually measured with specialized instruments, rather than taking many measurements by hand.

Audio amplifiers



The real output impedance of a power amplifier is usually less than 0.1 ohms, but this is rarely specified. Instead the value is "hidden" within the damping factor parameter, which is:

$$DF = \frac{Zload}{Zsource}$$

Solving for Z_{source} ,

$$Zsource = \frac{Zload}{DF}$$

gives the small source impedance (output impedance) of the power amplifier. This can be calculated from the Z_{load} of the loudspeaker (typically 2, 4, or 8 ohms) and the given value of the damping factor.

Generally in audio and hifi, the input impedance of components is several times (technically, more than 10) the output impedance connected to them. This is called impedance bridging or voltage bridging.

In this case, $Z_{load} >> Z_{source}$, $DF > 10$

In video, RF, and other systems, impedances of inputs and outputs are the same. This is called impedance matching or a matched connection.

In this case, $Z_{source} = Z_{load}$, $DF = 1/1 = 1$

The output impedance is not the same as the rated output impedance. A power amplifier may have a rated impedance of 8 ohms, but this does not mean the output impedance is of that value. The rated output impedance is simply that impedance into which the amplifier can deliver its maximum amount of power without failing.

See also

- Impedance
- Input impedance
- Damping factor
- Voltage divider

External link

- Calculation of the damping factor and the damping of impedance bridging

Some articles mentioning "Output impedance":

Audio system measurements	Electric violin	Input impedance	Nominal watt	Source impedance
	Fanout	Internal impedance	Operational amplifier	Source resistance

Clocked logic
Current source
Damping factor
Impedance bridging
Impedance matching
Internal resistance
Nominal impedance
Output resistance
School Science Experiment - Demonstrating the properties of waves on an Oscilloscope
Tri-state buffer

Previous **Encyclopedia Browser** **Next**

Outlook, MT
Outokumpu
Outokumpu Group
Outokumpu, Finland
Outpatient commitment
Outpost (computer game)
Outpost 26
Output
Output (economics)
Output feedback
Output resistance
OutRage!
Outrapo
Outreau
Outremer
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Outremont (electoral district)
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Outrider
Outrigger

Full Dictionary Browser

outpope the Pope
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Output
Output (comp.)
Output (enc.)
Output (economics) (enc.)
output contract
output device
output device (comp.)
Output feedback (enc.)
output file
output program
Output resistance (enc.)
output routine
output signal
output-to-input ratio
Outquench
outrace
Outrage
Outrage (law)
OutRage! (enc.)
outraged
outrageous
outrageously
outrageousness
outran
Outrance
outrange
outrank
Outrapo (enc.)
Outray

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ATTACHMENT D

Pages 1-6

AUDIO AMPLIFIERS, Pages 25-30
IRE Transactions on Audio

Audio Amplifiers*

FRITZ LANGFORD-SMITH†

Summary—**In this paper the design and testing of audio amplifiers is discussed. Attention is also given to the question of comparing the performance of different amplifiers and to the lines along which future investigation should proceed.**

Introduction

IT HAS BEEN assumed frequently that amplifier design is now quite conventional and that the real problems in audio frequency reproduction are associated with loudspeakers and acoustics. However, recent investigation into amplifier design has revealed a series of problems with no direct indication as to how their solution might be obtained. This paper describes a number of these problems and suggests an approach to the solution of some of them.

This paper is limited to a discussion of "main" amplifiers as distinct from preamplifiers since, in general, the most serious design problems in a complete audio frequency reproducing system occur in the main amplifier. Preamplifiers may assume many different forms according to the requirements of each particular application but, by good design, the nonlinear distortion in the preamplifier can be, and should be, less than that of the main amplifier.

It is generally agreed that a good "main" amplifier should possess the following characteristics:

1) Low nonlinear distortion and hence low harmonic distortion and low intermodulation distortion. Anything in the nature of a sharp kink in the linearity characteristic (input voltage vs output voltage) has a particularly distressing effect on the listener—far in excess of that indicated by the usual measurements of percentage distortion—and is therefore to be avoided where good fidelity is desired.
2) Substantially uniform frequency response over the whole audio range.
3) Sufficient maximum power output to handle peak power requirements under anticipated operating conditions over the whole audio range without noticeable distortion.
4) A good "overload" characteristic—that is, the distortion at outputs above the rated maximum power output should not increase at an excessive rate.
5) Sensitivity sufficient to provide the rated maximum power output with an input of not more than 1 or 2 volts.
6) Ability to reproduce any likely forms of transients without serious change in waveform.
7) The amplifier should not add to the information with which it is presented, for example, by overshoot, damped oscillations, etc.
8) Low output resistance—not greater than 20 per cent of the nominal load impedance.
9) Very low hum level.
10) Very low noise level. In most cases the noise contributed by the main amplifier is negligibly small compared with that from the preamplifier.

Amplifier Design Considerations

Output Valves

Effects of Loudspeaker Load: All amplifiers of the types being considered are intended to drive a loudspeaker. A very few are designed for operating one and only one loudspeaker, but the vast majority are intended for use with any one of a wide range of loudspeakers. A loudspeaker presents to the amplifier an impedance which may vary normally by a ratio of 10 to 1 while one world-famous high-fidelity loudspeaker varies by a ratio of 20 to 1. In addition, the loudspeaker impedance is reactive over most of the frequency range, presenting an elliptical loadline to the output tubes.

The effects of these variations, both in impedance and phase angle, are minimized by the use of push-pull Class A triodes, but are serious with pentodes and beam power tetrodes. The effects of a 10 to 1 variation in load impedance for purely resistive loads are shown in Figs. 1 to 3 inclusive. Fig. 1 shows the composite characteristics for a typical pair of push-pull Class A triodes. Fig. 2 shows the same characteristics for a pair of beam power amplifiers. A generally similar effect also occurs with pentodes. It can be seen that the triode characteristics are much more linear than those of the beam power tube. The linearity of the latter's characteristics may be improved if the screens are connected to taps on the plate winding of the output transformer. This arrangement is known as the "ultralinear" amplifier and typical characteristics for a pair of pentodes are shown in Fig. 3.

Pentodes vs Triodes: Pentodes have the following advantages over triodes:

1) They are more sensitive, requiring less input voltage for the same power output.
2) They have greater plate circuit efficiency, even when the screen power input is included.
3) They have good "cushioning" effect when approaching the overload point, and the rise in distortion is gradual.

* Reprinted from the May, 1956 issue of *Proc. IRE Australia.*
† A. W. Valve Co. Pty. Ltd., Sydney, N.S.W., Australia.

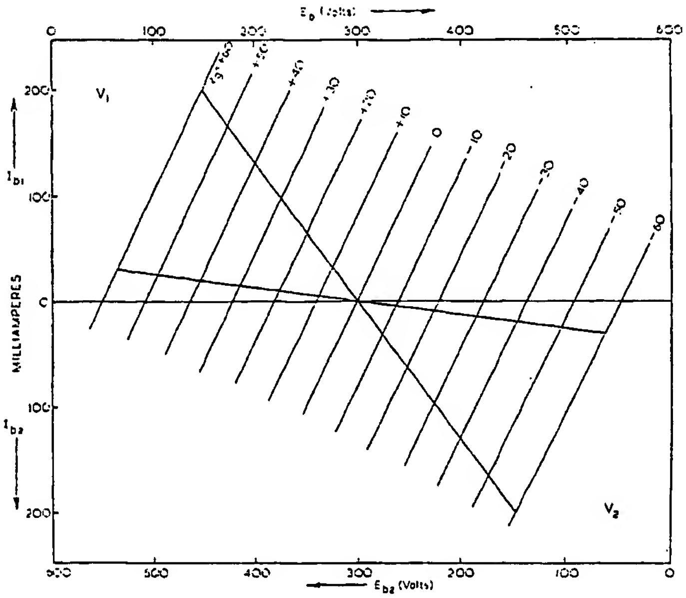

Fig. 1—Composite characteristic curves for two triodes connected as a Class A push-pull amplifier. Load lines for resistance loads of 3000 ohms plate to plate and 30,000 ohms plate to plate are shown.

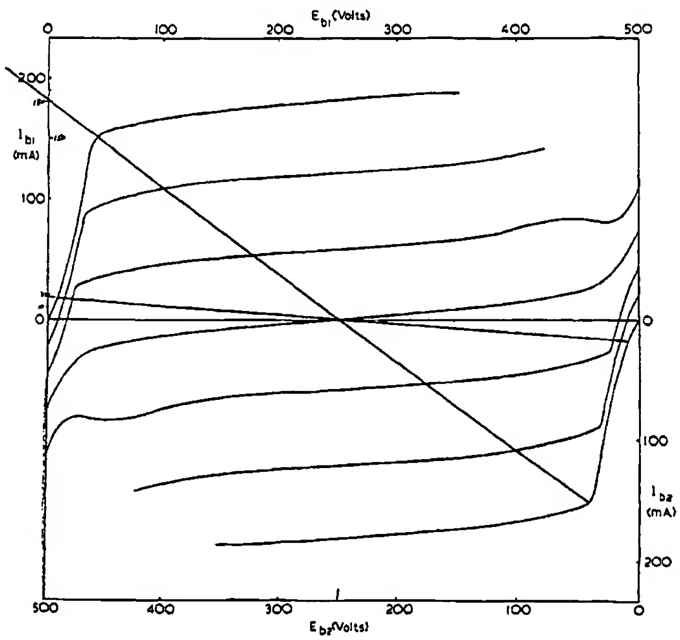

Fig. 2—Composite characteristic curves for two beam tetrodes connected as a Class A push-pull amplifier. Load lines for resistance loads of 5500 ohms plate to plate and 55,000 ohms plate to plate are shown.

As a result pentodes are very widely used in public address systems and medium fidelity amplifiers.

In high-fidelity amplifiers pentodes have the following disadvantages compared with triodes:

1) They are very sensitive to loudspeaker impedance variations; above and below 400 cps, power output must be reduced to limit distortion to the same as that at 400 cps. Consequently a much larger moninal power output is required with pentodes for comparable performance on a loudspeaker load.

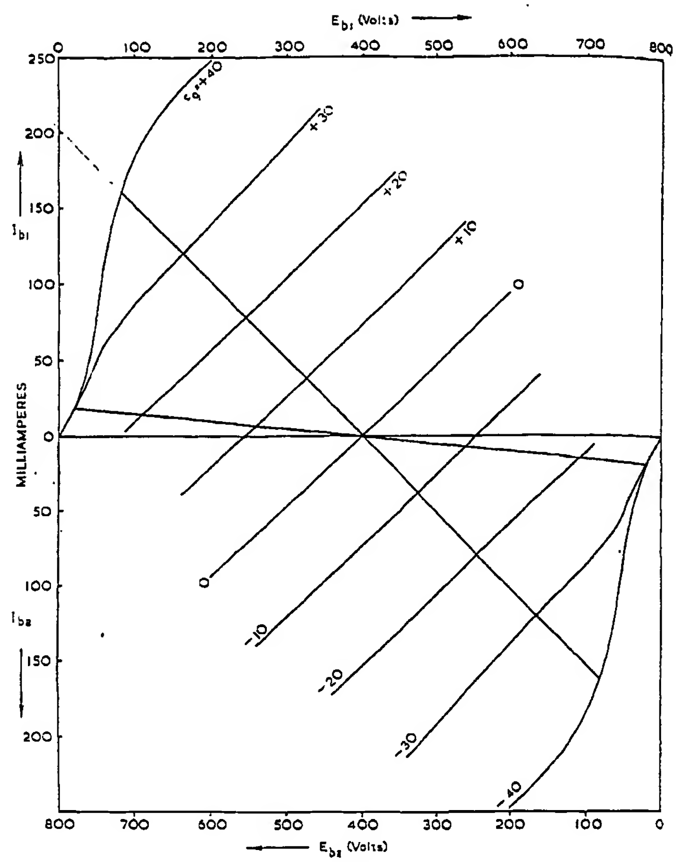

Fig. 3—Composite characteristic curves for two pentodes operated as an "Ultralinear" amplifier. Load lines for resistance loads of 8000 ohms plate to plate and 80,000 ohms plate to plate are shown.

2) In amplifiers of the 15-watt class, it is possible to use pentodes or beam power tetrodes which give the required power output and operate with equal plate and screen voltages. For higher power outputs the usual arrangement is to use a screen voltage lower than the plate voltage, and the regulation of the screen circuit then becomes a problem. Various ways of obtaining good regulation of the screen circuit have been developed but the best methods add appreciably to the total cost.
3) With pentodes the linearity characteristic always shows a gradual curvature over a considerable portion of its length and the slope of the characteristic at maximum rated power output is appreciably less than that at low levels. Consequently the reduction in distortion due to negative feedback at maximum output is considerably less than that at low levels. A greater degree of feedback is therefore required than would be anticipated from the simple theory of feedback. This effect does not occur to any appreciable extent with triodes such as in the Williamson amplifier, which has a substantially straight linearity characteristic even without feedback.

With triodes it is possible to drive quite a distance into the grid current region, with almost perfect linearity so

far as the plate characteristics are concerned, provided a sufficiently low impedance driver stage is used. As a result the overloading characteristics are very good. One way of achieving the low impedance driver is by using a push-pull cathode follower although this method is of very little value with pentodes.

It is the author's opinion that, other factors being equal, push-pull triodes are superior to pentodes or beam power tetrodes for the reasons stated. However this optimum performance is obtained at a cost—at least the additional cost of a larger power supply.

Much ingenuity has been shown in the design of amplifiers using pentodes or beam power tetrodes in an attempt to produce results approaching those obtained with triodes. In this field there is strong competition between pentodes operating as pentodes and those operating as so-called "ultralinear" amplifiers. At this stage it is difficult to quote a quantitative comparison, but the "ultralinear" circuit is being adopted widely in both England and the USA for high-fidelity amplifiers. It has the advantage of extreme flexibility of performance merely by moving the tapping point on the output transformer.

Matched Tubes: Certain amplifiers give their specified distortion values only if matched tubes are used but this condition is highly undesirable. The Williamson amplifier requires tubes matched within 5 ma plate current, but the specified distortion of 0.1 per cent is obtained only when the two plate currents are closely matched by using the potentiometer provided. Unfortunately, the tubes tend to drift apart, resulting in increased distortion, and it is unusual for such an amplifier to be checked periodically.

The Leak amplifier Model TL/12 does not require matched tubes nor does it rely on balancing controls, and yet its distortion on a resistive load is less than 0.05 per cent.

Certain other makes of amplifiers also claim to operate within specified distortion limits without requiring matched tubes, but in practice all of them are found to have considerably higher distortion. It seems that the two main features providing for satisfactory operation with unmatched tubes are the design of the output transformer and the use of separate cathode resistors, each separately by-passed.

Feedback

Point from Which the Feedback is Taken: Feedback may be taken from either the primary, the secondary, or a tertiary winding of the output transformer. The primary winding is the simplest and safest to use, since it does not introduce serious problems with instability. Its defects are that it does not reduce distortion caused by the transformer core, and that it results in a high hum level, hence requiring more elaborate filtering. The high hum level is caused largely by feeding back to some earlier stage the full hum voltage on the plates of the output tubes.

The best method for the reduction of distortion is to take the feedback from the secondary winding, but it introduces serious problems in stability usually accompanied by high peaks at low and high frequencies, unless only a small degree of feedback is used. These peaks are due to the large phase shifts which occur in output transformers at very low and very high frequencies, resulting in positive feedback at those frequencies.

The use of a tertiary winding on the output transformer is only slightly inferior to using the secondary of the transformer but it has the advantage that a greater margin of stability is obtained. Its great disadvantage is that a special transformer is required.

Multiple Loops: Most present-day designs have only one main feedback loop—usually from the output to the cathode of an earlier stage. Actually there is a small but useful, subsidiary loop caused by the unby-passed cathode resistor, which not only adds feedback but also helps to improve the stability. It seems that modern design will tend towards the use of multiple loops. One good arrangement comprises two partially-overlapping loops with a third subsidiary loop. This gives the required reduction in distortion with improved stability. The Leak TL/12 amplifier has three loops, both first and second stages having local loops which are enclosed within the main loop over the complete amplifier.

Combined Positive and Negative Feedback: In the usual form, positive feedback is used to increase the gain of the first stage, and over-all negative feedback is used to reduce the distortion. This method seems to have quite a useful future, not only for economical amplifiers, but also in the fairly good fidelity class. It is possible to control the attenuation of the stage employing positive feedback at very low and very high frequencies to improve the stability margin of the whole amplifier.

Transients

In musical reproduction the amplifier is forced to handle a succession of transients of many waveforms, which should be reproduced by the amplifier without distortion of form. In order to achieve this objective the following characteristics are necessary: a rapid rise, small overshoot, very small phase shift, and a slow rate of fall of the "flat top."

The most common method used in the laboratory for determining response to transients is the square wave. All amplifiers give better square-wave response from an electronically regulated plate supply, since an ordinary filter condenser is not capable of maintaining full voltage over the half cycle, especially at low frequencies.

An amplifier required to give good square wave response from 50 to 15,000 cps must possess substantially uniform gain, without peaks, over a very wide frequency range. The precise bandwidth required for a specified performance cannot be stated on present knowledge but all known amplifiers in this class appear to have a substantially uniform response from below 5 cps to about

200 kc. The testing of amplifiers with square wave input voltage is described in the next section.

A sawtooth waveform is approximately equivalent to a square wave of half the frequency, and therefore provides a much more severe test. The Williamson amplifier distorts a 50 cps sawtooth wave, although the reproduction is quite good when the time constant of the inter-tube coupling is increased four times. Good reproduction of some particular waveforms (*e.g.*, square wave or sawtooth) implies very low phase angle shift, since, for example, the phase angle of the twentieth harmonic is 20 times that of the fundamental. For example, one degree phase shift of the fundamental is equivalent to twenty degrees phase shift of the twentieth harmonic, and the twentieth harmonic of such waveform is quite appreciable.

Stability Margin and Peaks in Gain[1]

It is desirable to have a large stability margin under any possible condition of operation with any value of resistive, inductive, or capacitive source or load impedance—including open and short-circuited conditions. Stability margin may be defined as the increase in feedback, expressed in decibels, which may be applied before sustained oscillations are set up immediately following a large transient input signal. Most feedback amplifiers have their lowest stability margin when their normal load resistance is shunted by a particular value of capacitance and this condition is closely linked with the height of peaks in gain.

The peaks in gain due to feedback which occur at very low and very high frequencies should not, in the author's opinion, rise appreciably above the gain level at 1000 cps. However, some designers (including Williamson) allow one of the peaks to rise up to 6 db above the 1000 cps level on a resistive load, which means that, on a loudspeaker load, one or both peaks may rise considerably higher. When the high-frequency peak is somewhat above the frequency at which the particular loudspeaker changes over from inductive to capacitive impedance, it is likely that the high-frequency peak will be accentuated. Considerable differences are to be expected in the height of the high-frequency peak with various loudspeakers, and it seems preferable for amplifier design purposes to use a normal resistive load shunted by capacitance, the value of the capacitance being determined by trial of successive increments (of the order of ± 20 per cent) to give the maximum peak height. In this way the worst possible condition may be obtained. The effect of any appreciable high-frequency peak, even +2 db, on a square wave input is to produce overshoot, followed by damped oscillation commonly known as "ringing" at the frequency of the peak.

In many cases the low-frequency peak is higher than the high-frequency peak, and its effects on performance are more serious. The presence of a low-frequency peak with a level of about +3 db or more is usually associated with a fluctuation in level when a high-frequency tone is instantaneously decreased from maximum to say half output voltage. The simplest means of testing for this condition appears to be the application of a 10,000 cps tone switched at 50 cps from maximum to half voltage.

Loudspeaker Damping

A low amplifier output resistance assists considerably in increasing loudspeaker damping in the vicinity of the bass resonance frequency but has no beneficial effect at much higher frequencies. It is possible, by the use of combined positive and negative feedback, to reduce the amplifier output resistance to zero, but this provides very little improvement in the damping compared with a value of the order of 10 per cent of the load impedance. With loudspeakers having high efficiency and high flux density it is possible to reach or even exceed critical damping. With a low efficiency and low flux density loudspeaker there is no hope of reaching critical damping, although even a partial degree of damping is beneficial.

Distortion

It may be asked why it is desirable to have an amplifier with harmonic distortion of the order of 0.1 per cent and whether it is possible to detect aurally such a low level of distortion. Tests by Dr. Olson[2] have shown that approximately 1 per cent total harmonic distortion is the lowest amount perceptible, under the conditions of his tests. These tests were conducted on single triodes and single pentodes and, although no details are given, it is obvious that the test amplifiers did not include any sharp kinks in the linearity characteristics (which only occur in an amplifier when a tube is completely cutoff during part of the cycle), and that there was no incipient instability. Consequently this figure of about 1 per cent is not of general application, and some amplifiers with less than 1 per cent total harmonic distortion are likely to have perceptible distortion.

The total distortion heard by the listener is the sum of the distortion levels in the source, amplifier, and loudspeaker. Therefore any reduction of the distortion in the amplifier is generally desirable and beneficial, although a very small reduction would probably not be noticed by the listener. Another reason for the desirability of a low distortion level is that it gives a comfortable margin for deterioration during the life of the amplifier, particularly in the output stage.

THE TESTING OF AMPLIFIERS

Electrical Testing with Steady Sine Wave Input

This includes all the usual tests for nonlinear distortion, power output, frequency response, output resistance, hum and noise etc. Unfortunately, these tests do not give a true representation of the performance of the

[1] Further experience since the date of submission has shown the importance of avoiding positive feedback at any frequency. This is indicated by a higher response level with feedback than without, at the frequency in question.

[2] H. F. Olson, "Elements of Acoustical Engineering," D. Van Nostrand Co., Inc., New York, N. Y., 2nd ed.; 1947.

amplifier under conditions existing in the reproduction of music. In particular, three features are criticized strongly:

1) The tests for distortion (both total harmonic distortion and intermodulation) do not give values which are truly indicative of the subjective effect on the listener.
2) They are carried out normally with a constant resistive load, and are therefore quite misleading when used to compare different types of output tubes, such as triodes and pentodes.
3) They do not indicate the performance with transient input voltages, this being the usual condition when reproducing music or speech. In the case of Class AB operation, the results obtained with transients depend on the immediate past history of the amplifier, that is, the type of input signal, which has been applied during the preceding moments and its effect on the static grid bias and plate currents.

In addition to these routine tests, it is highly desirable that the gain of any feedback amplifier be measured and plotted, both with and without feedback, over the whole effective frequency band of the amplifier, including both low- and high-frequency peaks. In the case of high-fidelity amplifiers in the Williamson class it is necessary to cover from about 1 cps to 500 kc, and this involves serious problems both with oscillators and measuring equipment.

Electrical Testing with Pulse Type Input Voltages

The most practical laboratory methods for simulating the types of transients existing in speech and music utilize either repetitive pulses or a white noise input. The former includes square wave, sawtooth and other forms and also a high-frequency tone (10,000 to 20,000 cps) which may be pulsed either on/off or pulsed from maximum to reduced-amplitude. A square wave has both a steep rise, which is a transient, and a flat top which is not a transient. Significant features for measurement are the rise time in microseconds (from 10 to 90 per cent of the flat top height, conveniently measured at 10 or 20 kc), the percentage overshoot, the recovery time after the overshoot, and the percentage fall of the flat top measured at some convenient low frequency such as 50 cps. The oscilloscope should give good performance up to 500 kc. It is unfortunate that there is no single figure which can be quoted to indicate the distortion of a square wave.

Although white noise input has been used for the transient testing of both loudspeakers and amplifiers, its peculiar qualities make it a very difficult tool for the amplifier designer to handle, both in use and in interpretation of the results. Consequently no comment is offered at this stage.

Subjective Tests

Subjective tests with a critical listener are vitally important in evaluating the performance of an amplifier particularly in view of our present limited state of knowledge regarding objective electrical tests. It is well known that some amplifiers with less than 1 per cent measured total harmonic distortion at 400 cps give very poor results on a listening test. Some of the many possible causes of this effect include parasitic oscillations over a small portion of the cycle, a sharp kink in the linearity characteristic, and damped oscillations following a sharp transient.

Reliable conclusions from listening tests are obtained only when care is taken with the equipment and the methods used for the test. For comparing two or more main amplifiers with essentially flat frequency response, all the equipment other than the main amplifier (*i.e.*, record player, preamplifier, and loudspeaker) should be common to all tests, and a suitable volume control should be placed before the input terminals of all, or all but the most insensitive, main amplifiers. These volume controls should be adjusted by ear to give identical loudness for all amplifiers under test.

The best available loudspeaker should be used for all the tests; it should have wide frequency range and low distortion, otherwise distortion in the loudspeaker will prevent aural detection of distortion in most amplifiers. The listener should be seated on or near the axis of the loudspeaker, at a distance of 4 to 6 feet. At a greater distance the room characteristics tend to dominate the direct sound. The listener should have in his hands both the volume control and changeover switch. Comparisons should be made at all levels, including overloading, and various types of program material should be used, both speech and music.

It is difficult to arrange a "fair" test when comparing amplifiers having widely different maximum output powers, since in most well-designed amplifiers the distortion decreases as the level is decreased. If the power ratio is two to one, it might be possible to connect two loudspeakers in parallel to the larger amplifier, one being placed in another room. The alternative of using a partially resistive load to absorb the excess power of the larger amplifier is not satisfactory except perhaps with Class A triodes.

Conclusion

No amplifier is perfect, or is claimed to be perfect. As with all other products, amplifier design is a compromise. Exceptionally fine performance may be obtained from a "laboratory" amplifier requiring matched tubes and periodical adjustment, but this is of limited interest.

Unfortunately at the present time there is difficulty in defining suitable tests for amplifiers and so it is extremely difficult to make fair comparisons between different types of amplifiers. Within very limited categories it is possible to make at least an approach towards a fair comparison, for example all pure Class A push-pull triodes may be compared on the basis of total harmonic distortion, performance on square waves, and on pulsed wave-train input voltages. But it is not possible, with our present limited state of knowledge, to compare per-

formance figures of Class A triodes with Class AB triodes, or to compare any type of triodes with pentodes.

This serious lack of knowledge, particularly about the transient performance of amplifiers, is seriously hindering both the design and the comparison of amplifiers. As a result, a long-term laboratory program is now being undertaken on the investigation of amplifier problems, among which are:

1) The operation of resistance-coupled triodes and pentodes following high-impedance stages; also more comprehensive and convenient forms for giving the distortion under a wide range of resistance-coupled operating conditions.
2) Methods of minimizing the distortion rising from the use of output tubes which are not specially matched.
3) A method of measuring nonlinear distortion in such a way as to give a true indication of the effect on a listener.
4) The development of a "dummy" loudspeaker load to be used for the measurement of distortion, power output, and gain vs frequency, which gives results closely approaching those obtained on a loudspeaker load.
5) The investigation of the relationship between the heights of the high- and low-frequency peaks and overshoot and other defects in the reproduction of square wave and pulsed wave-train input voltages, and to put these into the form of numerical values for comparison.

In conclusion, it is the author's hope that the contents of this paper will stimulate discussion on this subject which is of great interest to many people.

Loudspeaker Design and Application*

ARTHUR McLEAN†

Summary—**This paper is concerned with the problems involved in the design of loudspeakers and in the assessment of their performance. The incorporation of design data into speaker applications is also discussed.**

Introduction

MR. STEWART concluded his paper with the theme that the ear is the final arbiter. A wide difference exists between the performance as expressed by present-day instrumentation and that perceived by the ear, because in most cases too many unjustified assumptions and omissions exist in the former. As an example offered to explain this statement a modern amplifier has been analyzed below.

It is known that it handles single-frequncy sine waves down to 5 cps uniformly, yet where Fig. 1(a), opposite, shows a saw-toothed wave of 50 cps applied to the input, the output depicted in Fig. 1(b) is considerably altered. While the amplifier is known to handle single-frequency sine waves uniformly up to 100 kc, its output as depicted by Fig. 2(b) is different from its input shown in Fig. 2(a) when handling white noise of uniform energy per cycle from 40 to 16,000 cps. The conditions under which the tests were conducted are as follows:

1) The oscillograms are photographs of the trace on a high-quality cathode-ray oscillograph.
2) While two beams and their associated amplifiers are available on the equipment, one system only is used in case the two systems do not provide identical performance on complex waves.
3) The amplifier is terminated in a fixed resistor equal to the nominal value of its output impedance.
4) The peak-to-peak values of voltage applied are well below the overload point of the system.
5) The gain of the cro, not the amplifier under test, is adjusted to give a suitable amplitude in each case.

The selection of a saw-toothed wave form as a basis for testing is not due simply to chance. It is the fundamental wave form of speech and animal sounds as well as that of all bowed musical instruments. When a blockage is caused by the vocal cords being closed, air pressure is built up until the cords open and the pressure decreases. To simulate these vocal sounds a steady flow of direct current from a battery is modified in a relaxation oscillator, where the voltages developed depend upon the charging and discharging of a capacitor by a critically-controlled trigger circuit. Thus Fig. 3(a) shows the wave form, using a probe microphone at the vocal cords and Fig. 3(b) depicts the wave form at the lips after the basic saw-toothed wave form is modified by a series of more than the twenty resonant chambers between the larynx and the lips. Thus a suitable synthetic wave form of speech comprises a sawtooth with super-

* Reprinted from the May, 1956 issue of *Proc. IRE Australia*.
† Amalgamated Wireless (A/sia) Ltd., Sydney, N.S.W., Australia.